NREL
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2014 CEC Natural Gas Vehicle Research Roadmap Update

Natural Gas Vehicle Technology Forum

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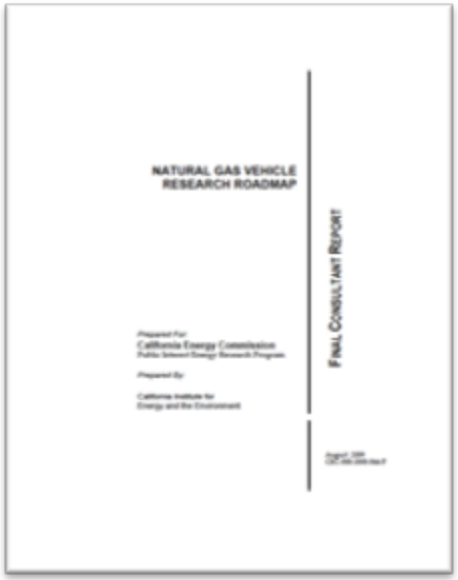
Roadmap Overview and Objectives

Objective: Inform natural gas vehicle R&D investment decisions made by the California Energy Commission (CEC) and stakeholders to promote increased ratepayer benefits



NGVRR 2009

Developed in 2008-2009 to provide "most needed, major natural gas vehicle related research, development, demonstration, and deployment" in the following areas:

- Engine development and vehicle integration actions
- Fueling infrastructure and storage actions
- Technical and strategic studies actions

NGVRR 2014

Updates previous NGVRR to:

- Identify emerging opportunities
- Identify fundamental changes in the NGV market and associated technologies
- Reassess the priority of previously identified technologies given developments that have happened over the past 5 years to develop a "new baseline".

Guiding Direction and Legislation

Senate Bill 1250

Enables PIER funds to be used for advanced transportation technologies that reduce air pollution and GHG emissions beyond applicable standards as a benefit to natural gas ratepayers

Assembly Bill 1007

Directed CEC to develop a State Alternative Fuels Plan. Plan presents strategies and actions California must take to increase the use of alternative transportation fuels including natural gas

Assembly Bill 32

Calls for approximately 36% of the state's 2020 GHG reduction targets to come from the transportation sector

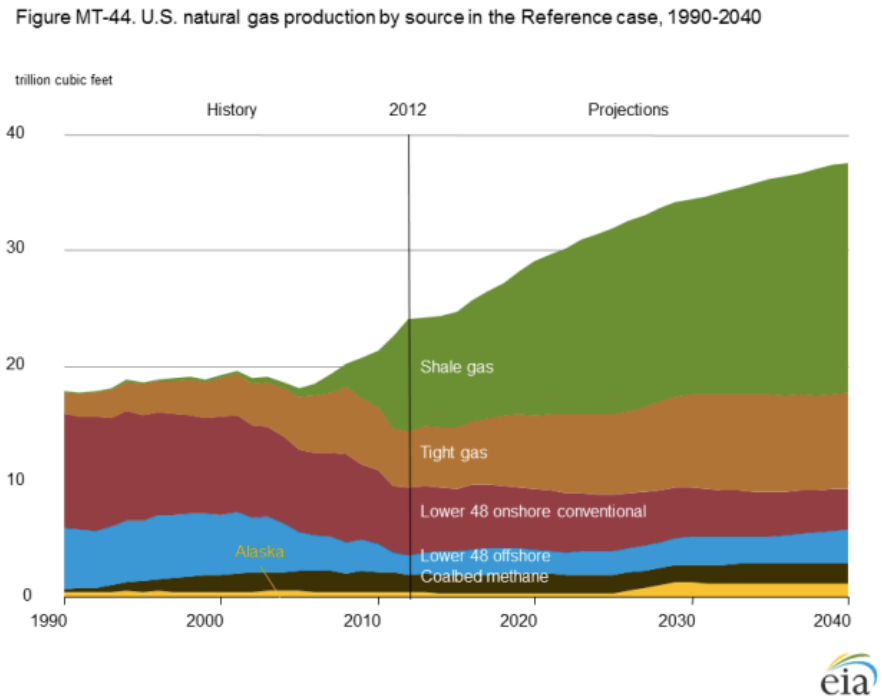
Assembly Bill 118

Created the California Energy Commission's Alternative and Renewable Fuel and Vehicle Technology Program. The statute authorizes the Energy Commission to develop and deploy alternative and renewable fuels and advanced transportation technologies based on the State Alternative Fuels Plan developed under AB 1007 to help attain the state's climate change policies.

NGV Market and Technology 2009-2014

Significant Increases in Natural Gas Reserves and Production Projections Have Created Downward Pressure on Prices

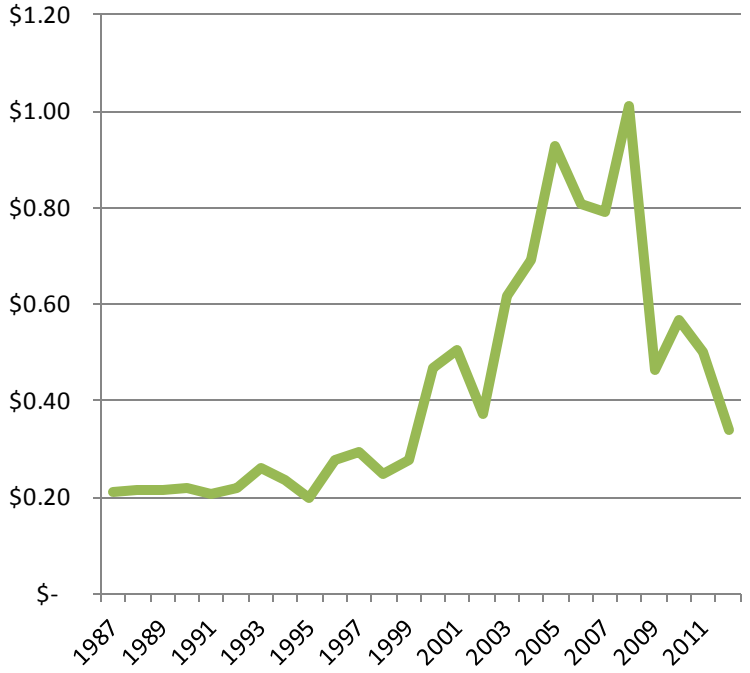
Historical and Projected U.S. Natural Gas Production 2040



Projected 2040 production is projected to increase 82% over 2009 levels

Source: U.S. Energy Information Administration

U.S. Natural Gas Wellhead Price ($/gge)



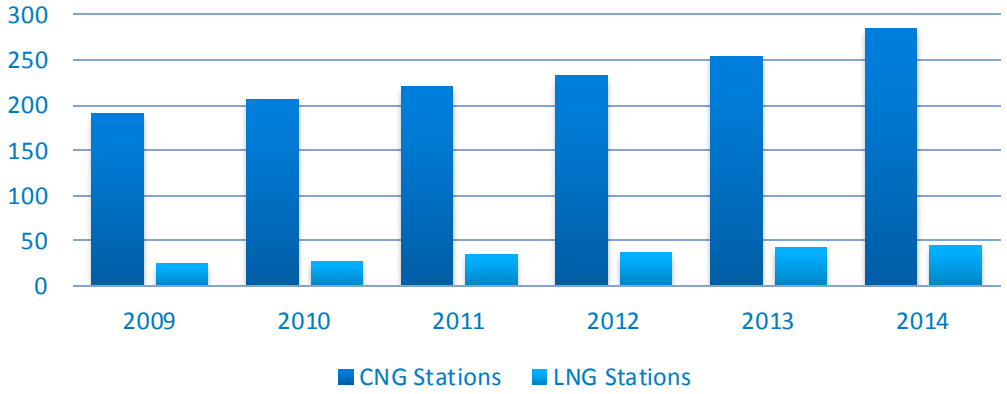
Wellhead prices for natural gas have dropped by 26% between 2009 and 2012 (66% since 2008)

Source: U.S. Energy Information Administration

NGV Market and Technology 2009-2014

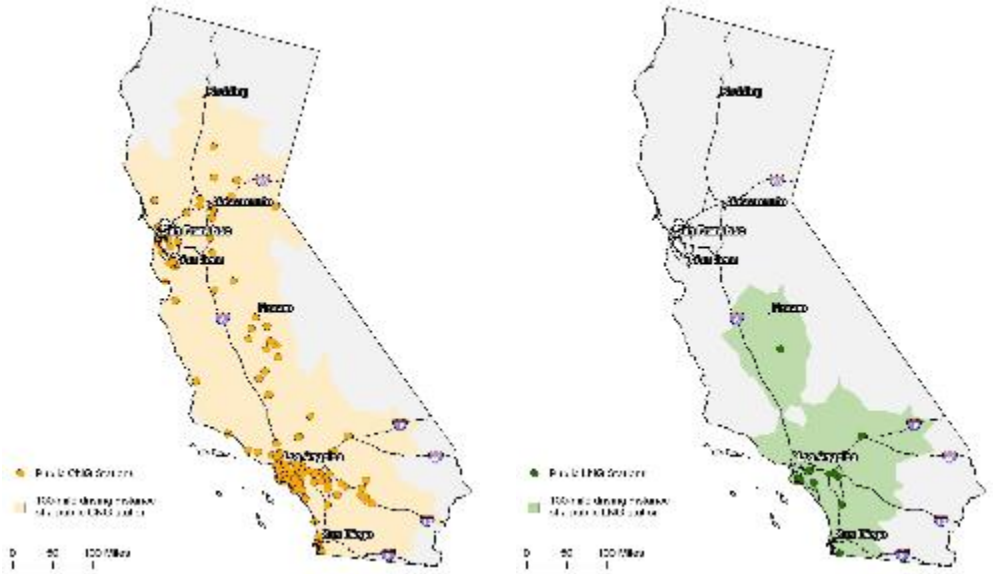
Steady Growth in Natural Gas Infrastructure Growth and Distribution

In 2009, there were 191 CNG stations and 25 LNG stations yin CA. By 2013, this number increased to 285 and 45 respectively



Source: U.S. Department of Energy Alternative Fuel Data Center

- Widespread public access to CNG for highway travel
- Robust CNG infrastructure in greater Los Angeles area
- Limited public availability of LNG

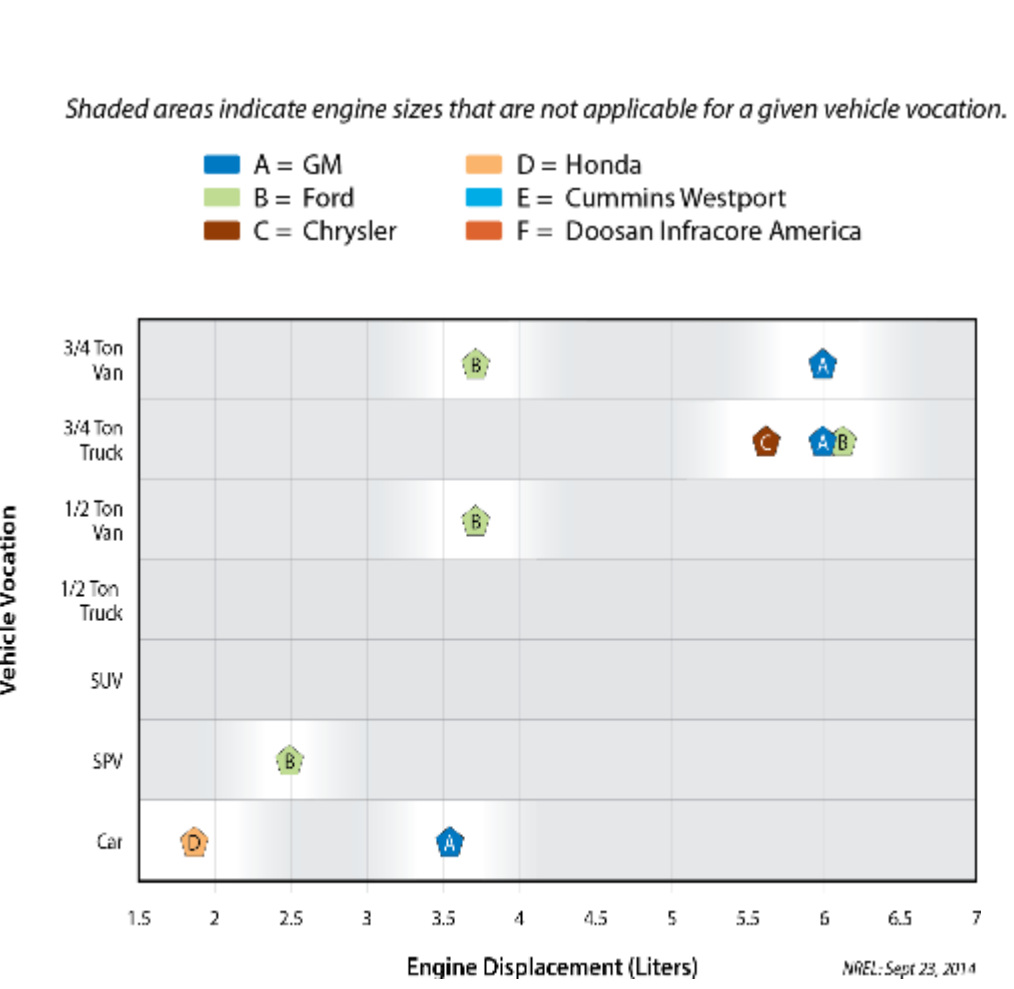


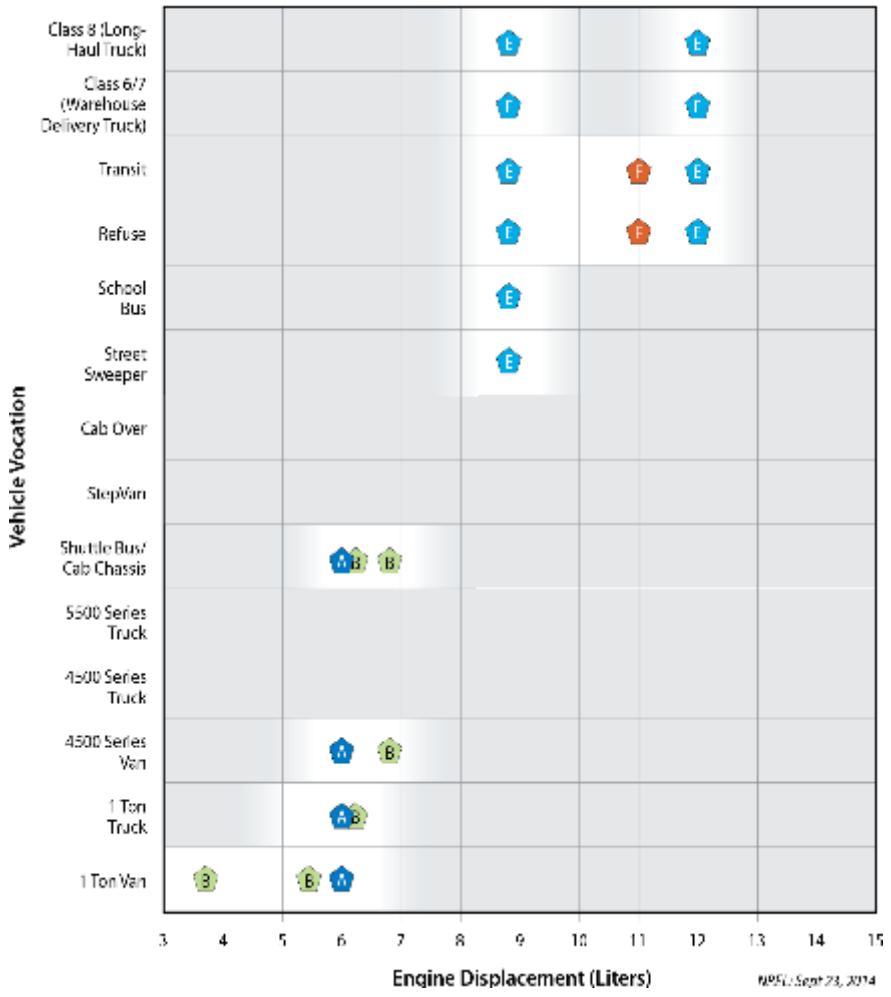
Source: U.S. Department of Energy Alternative Fuel Data Center

NGV Market and Technology 2009-2014

Significant Improvements in OEM Availability for MD/HD

Light-Duty ⟷ Medium/Heavy-Duty

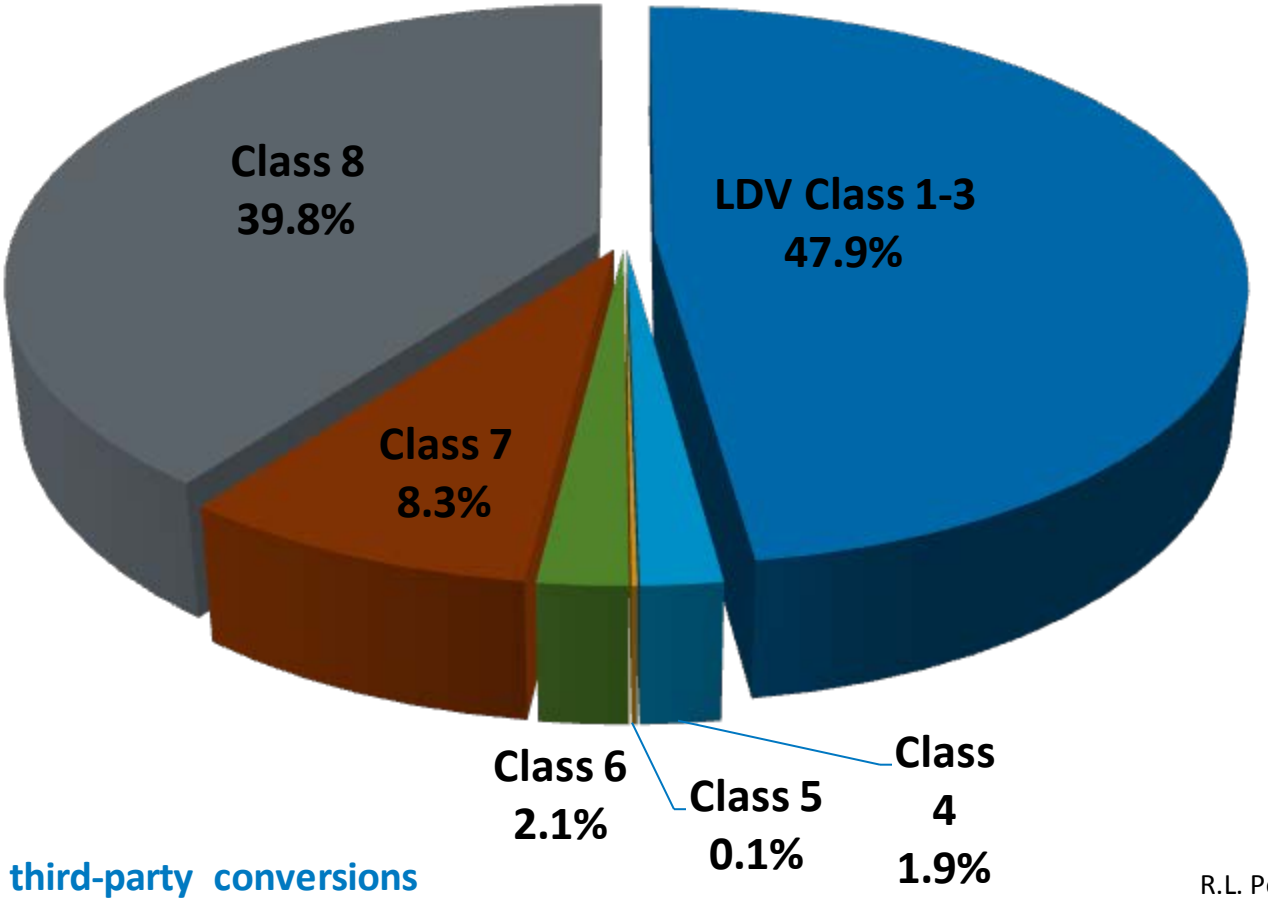




NGV Market and Technology 2009-2014

NGV Adoption Favors LD and HD NGVs, Less So MD

California Natural Gas Vehicle Distribution by Class. Total: 24,600 (2013)*



*Does not include third-party conversions

R.L. Polk VIO_2013

NGVRR 2009 Recommendations and Actions

Engine Development and Vehicle Integration Actions

- ✓ Integrate available natural gas engines into more models and applications by original equipment manufacturers (OEMs), in all weight classes.
- ✓ Develop a broader range of natural gas HDV engine sizes and applications.
- ✓ Develop a broader range of natural gas HDVs with improved engine economics, efficiency, and emissions.

Develop NGV versions of off-road applications.

- ✓ Develop a variety of hybrid natural gas HDVs.

Develop engine technology optimized for hydrogen-natural gas blended fuel.

Develop NGV homogeneous charge compression ignition (HCCI) engine technology.

Fueling Infrastructure and Storage Actions

Develop legacy fleet engine controls and/or fueling infrastructure upgrades to accommodate fuel variability.

Research an improved composite tank safety device/installation protocol to avoid rupture in a localized fire.

Develop improved handling, reliability, and durability of LNG dispensing and on-board storage.

Provide global positioning system (GPS) guidance to NGV fueling station locations and details statewide.

- ✓ Develop on-board lightweight, conformable, compact CNG storage at lower pressure and higher density.

Develop the next generation of home refueling for natural gas light-duty vehicles (LDVs).

Technical and Strategic Studies Actions

Confirm NGV economic, carbon, and emissions net benefits.

Create a clearinghouse of NGV demand and supply information.

- ✓ Institute a technology forum for NGV stakeholders to update RDD&D needs and priorities.

NGVRR 2014 Recommended R&D Priorities

NGVRR 2014 Summary Findings

NGVs have a significant opportunity to create and increase ratepayer value by leveraging abundant, low-cost natural gas

Key changes between 2009 and 2014 include:

- Positive, stable, market for natural gas resource
- Increase in natural gas engine availability and reliability
- Significant regulatory and policy developments that raise the bar for emissions and efficiency and have resulted in advanced in conventional technologies.

Specific R&D Opportunities Exist in the Following Categories:

- Range and natural gas storage
- Engine performance and availability
- Vehicle emissions and environmental performance
- Analysis and information sharing

NGVRR 2014 Recommended R&D Priorities

Innovation is Needed to Maintain Momentum and Increase Ratepayer Benefits

Natural gas vehicle technology, features, and performance will need to experience significant levels of innovation to keep up with incumbent and emerging technologies and meet future regulations including the following key topics:

1. Integration of existing high-efficiency engine designs and continued reduction in the "natural gas efficiency penalty"
2. Better quantification of natural gas vehicle emissions and improved and tailored emission controls and catalyst technology for natural gas
3. Improved pressurized gas storage performance, cost, and flexibility
4. Continued efforts to promote greater OEM availability of natural gas vehicles
5. Improved storage and infrastructure communications and performance to increase range and safety
6. The development of a separate roadmap to identify appropriate research targets for natural gas technologies for marine and rail applications

NGVRR 2014 Recommended R&D Priorities

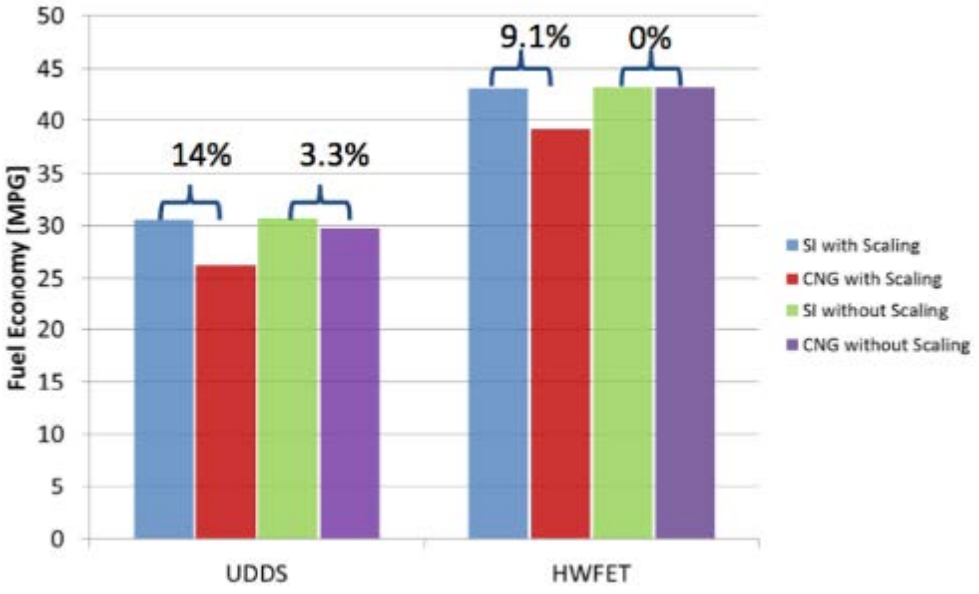
Address the Growing Efficiency Gap Between Natural Gas and Gasoline/Diesel

Increased fuel economy requirements have placed higher emphasis on efficiency performance

- LD efficiency gap estimated between 2-12%
- HD efficiency gap estimated between 15-20%

NGVs have not yet successfully incorporated the full suite of engine efficiency measures

Relative Fuel Economy Performance Between Natural Gas and Gasoline Engines



Source: Argonne National Laboratory (2012)

NGVRR 2014 Recommended R&D Priorities

Quantify and Improve Emissions Performance of Natural Gas Vehicles

Need to develop "new baseline" for relative tailpipe emissions.

- Current data is dated and does not allow for adequate assessment

Significant reductions in NOx will be required in some California air basins

- HD trucks present large source of current emissions inventory
- Impacts likely for both diesel and NGVs

Greenhouse gas targets are becoming more stringent

- Potential need to develop technology to address methane emissions

NGVRR 2014 Recommended R&D Priorities

Continue to Advance Efforts in On and Off-Board Storage

Range and storage continues to be a barrier

- Need for commercial adsorbent storage technology to continue ARPA-E work
- Cost reductions for carbon fiber storage are needed to reduce weight penalties
- Certification of conformable tanks will be needed to encourage better vehicle integration

LNG storage improvements are needed to address venting concerns and durability

Pressurized Gas Storage Container Characteristics

	TYPE 1	TYPE 2	TYPE 3	TYPE 4
STRUCTURE	Metal	Metal Liner Reinforced with Resin Impregnated Continuous Filament (Hoop Wrapped)	Metal Liner Reinforced with Resin Impregnated Continuous Filament (Fully Wrapped)	Resin Impregnated Continuous Filament with a Non-Metallic Liner
MOST COMMONLY USED	CrMo Steel	CrMo Steel with Glass Fiber	Aluminum with HP Glass and/or Carbon	HDPE Liner with Carbon
INDICATIVE COST – U.S.$/LITER	$3 to $5	$5 to $7	$9 to $14	$11 to $18
INDICATIVE WEIGHT – KG/LITER	0.9~1.3	0.8~1.0	0.4~0.5	0.3~0.4

Note: Evident weight reduction (up to 75%) in adopting Types 3 and 4, but comes at a cost.
Sources: CompositeMarketReports.com, CompositeWorld.com.

NGVRR 2014 Recommended R&D Priorities

Increase Performance, Efficiency, and Accessibility of Natural Gas Fueling Infrastructure

Home refueling options are limited and relatively expensive

- Need to present technology that is competitive on cost and performance with EV charging
- Home refueling technology becomes more attractive with low-pressure storage

"Smart" infrastructure can increase safety and performance

- Technology is needed to provide a "full-fill" faster
- Communications protocols can aid in addressing tank safety, fuel quality, and vehicle performance

On-site and mobile gas storage can increase utility and performance of NGV infrastructure

- On-site storage can be better utilized to enhance performance and provide backup in the case of an emergency

NGVRR 2014 Recommended R&D Priorities

Pursue a Separate Technology Roadmap for Marine and Rail Technologies

Marine, rail, and other high horsepower technologies present a sizable opportunity for LNG

- Marine and rail emissions are responsible for the 3rd and 5th largest share of NOx emissions in the South Coast Basin
- Technologies and infrastructure will likely be distinct from those needed for over the road vehicles.

Full List of Draft 2014 NGVRR R&D Recommendations

Range and natural gas storage

- Develop Low-Pressure, High-Density Natural Gas Storage Vessels
- Develop a Certification Process for Natural Gas Conformable Storage Tanks
- Increase Natural Gas Storage and Vehicle Integration
- Development of Low-Cost Carbon and Glass Fiber Storage
- Cost-Effective Home Refueling
- Develop Small or Modular Fueling Facilities
- Enhance On-site Storage
- Maximize Current Cylinder Utilization and Capacity
- Promote “Smart” Cylinders and Refueling Stations

Engine performance and availability

- Support Technologies for Direct-Injection in Light-Duty Vehicles
- Increase Competition and Choice in the Natural Gas Vehicle Marketplace
- Exploit Natural Gas Fuel Properties and Address Fuel Quality Discrepancies

Full List of Draft 2014 NGVRR R&D Recommendations

Vehicle emissions and environmental performance

- Develop Optimized Controls for Natural Gas
- Address LNG Storage Tank Venting
- Promote Further Development of Vehicle Hybridization Technologies

Analysis and information sharing

- Determine the Best Use of Natural Gas in Transportation
- Update Emissions Data on Natural Gas Vehicles
- Continue and Enhance Coordinated NGV Research and the NGVTF
- Identify Market Impact of Technology Developments

Finalizing the Roadmap

Process to Date

- Literature Review
- Initial Outline and Stakeholder Scoping Interviews
- Final Outline
- Draft Report

Next Steps

- Publication of Draft Roadmap for Review and Comment
- Public Workshop Held at CEC
- Final Publication of NGVRR

Thank You

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Learn more at
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